DESIGN BASIS ACCIDENT ANALYSES FOR SUNPP UNIT 1 AND RNPP UNIT 1

Presentation materials for

Annual Information Forum on Safety Assessment of NSSS with WWER and RBMK types of Reactor

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Developed by South-Ukrainian and Rivne NPP in cooperation with "Energorisk, Ltd"

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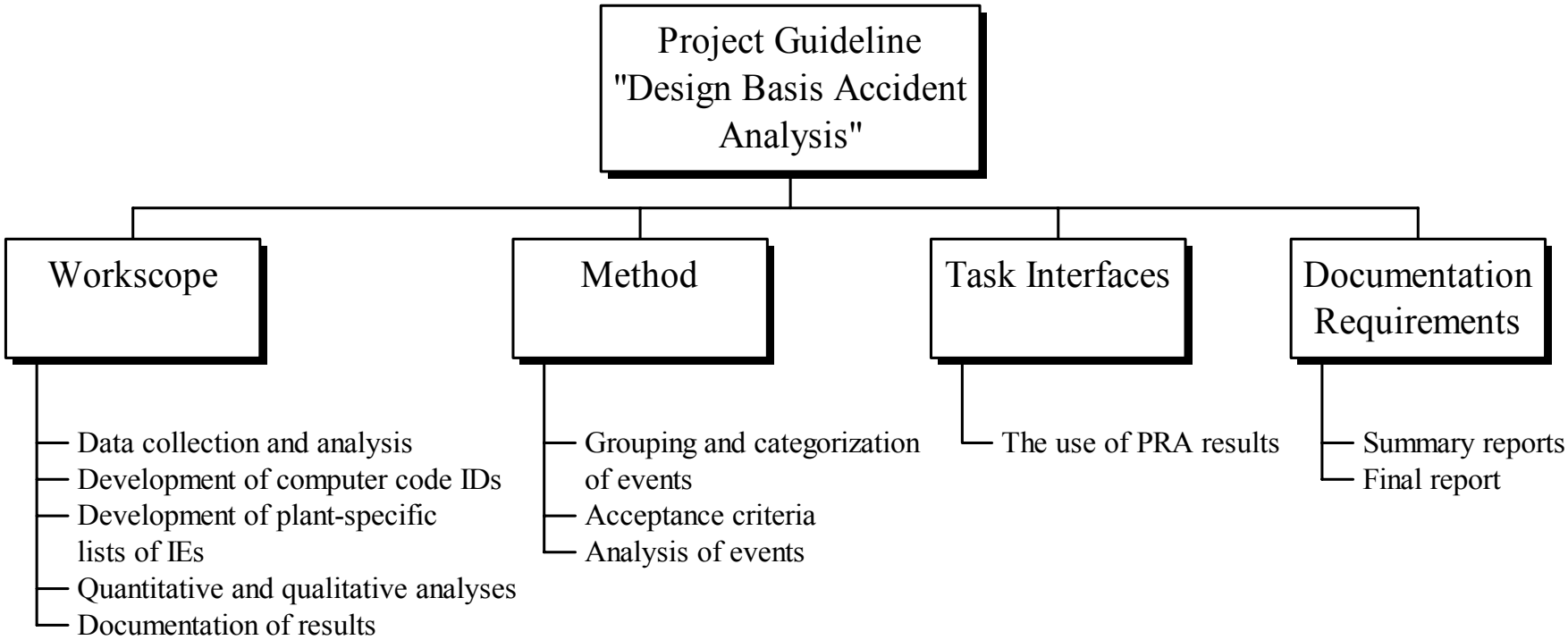
Objectives and Limitations

- Perform deterministic analyses using internationally accepted practice to support development of SAR Section “Accident Analysis” for SUNPP-1 (WWER-1000/302) and RNPP-1 (WWER-440/213)
- Violations during fuel and radioactive waste management are not included
- Analysis of reactivity and power distribution anomalies is performed with point reactor kinetics
- Radioactive release is calculated with limited level of sophistication

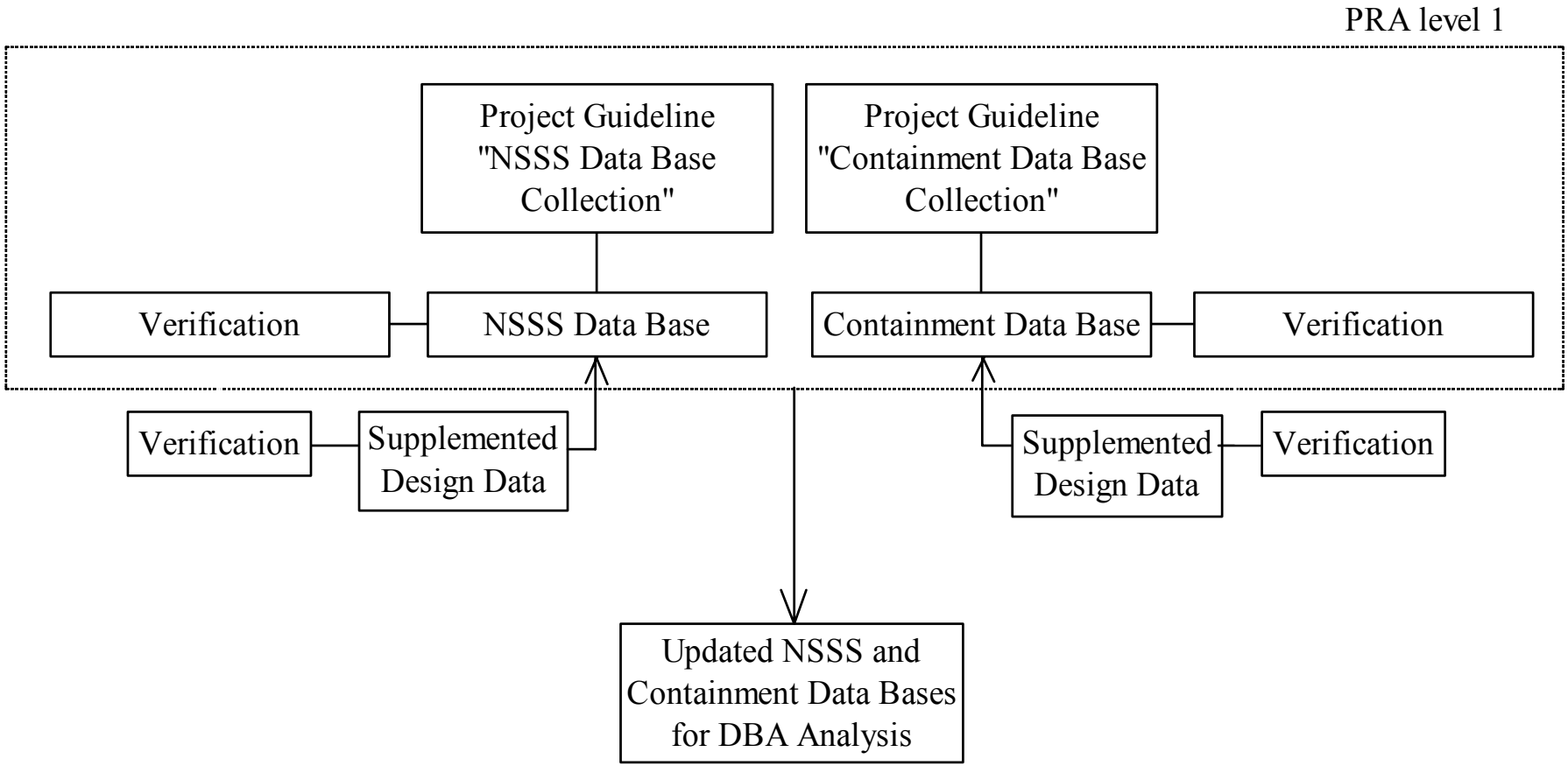
Methodology Basis

- Deterministic approach comparable to that used in international practice is applied, considering
  - Ukrainian regulatory documents
  - IAEA recommendations
- DBA Analysis is considered to be subject to quality assurance program, which includes a set of procedures and guidelines

DBA Analysis Organization

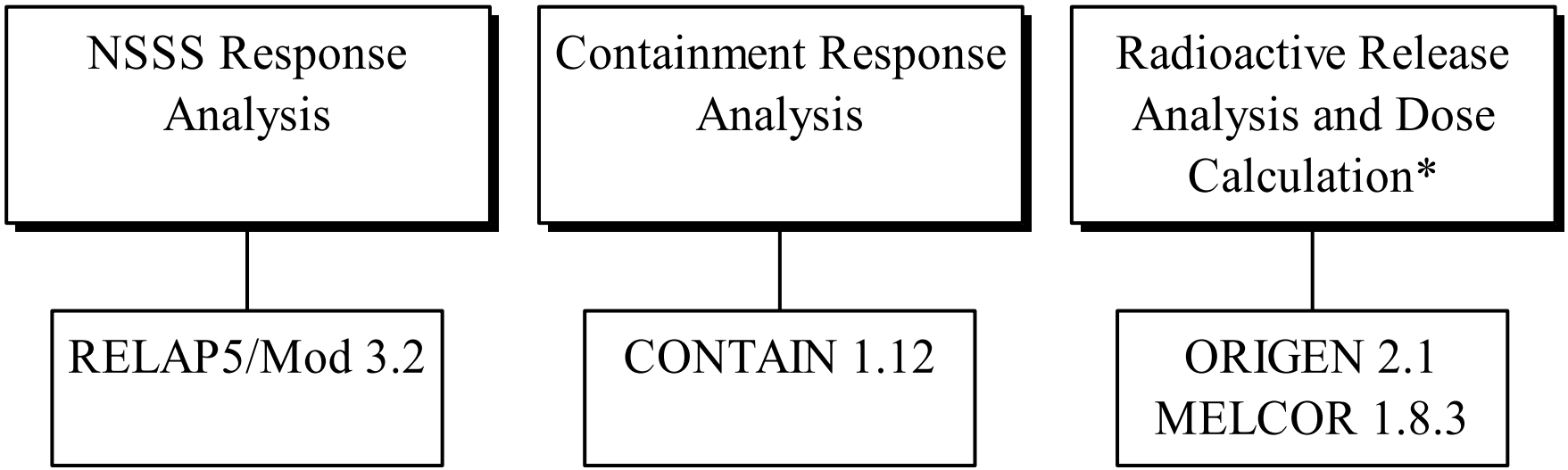


Data Collection and Analysis



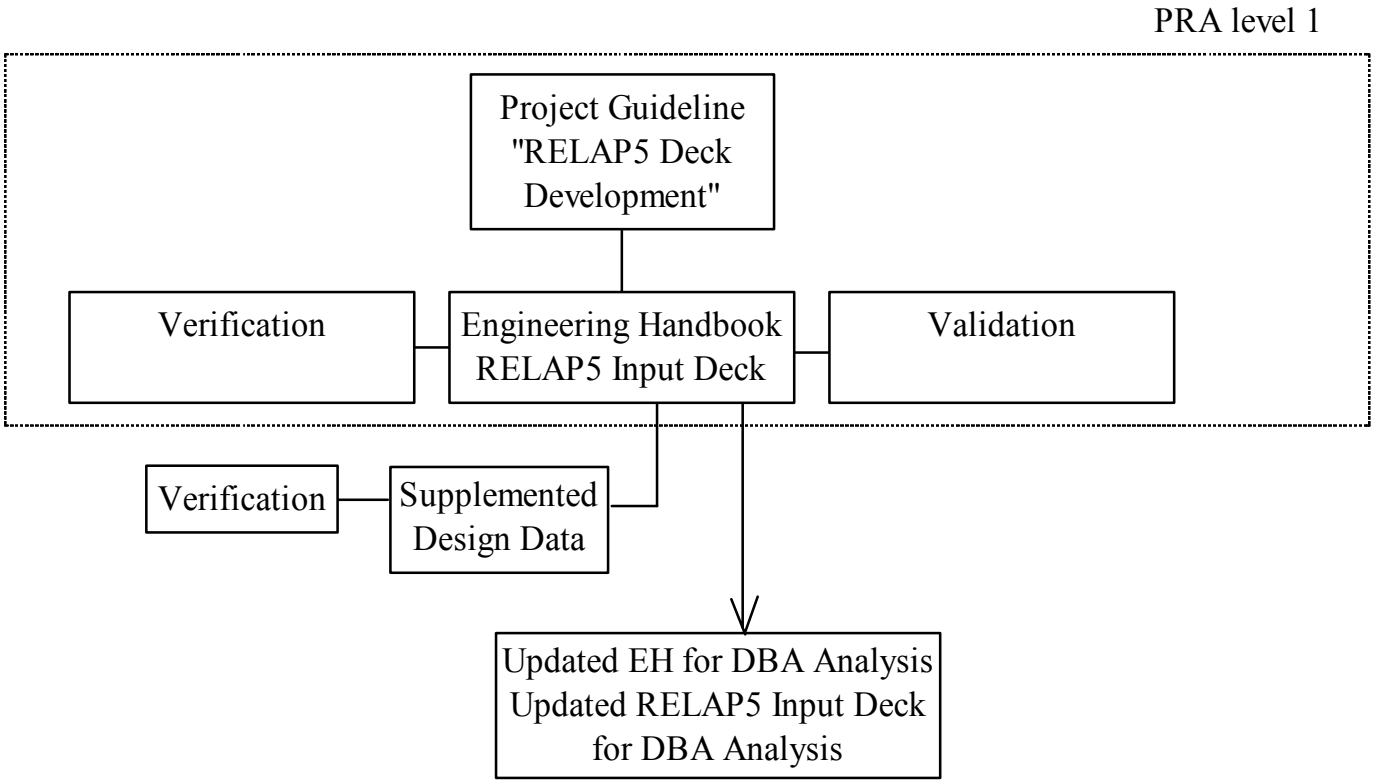
* Verification includes internal verification and external review

Computer Code Used



* ORIGEN calculates initial fission products inventory in the core, MELCOR gives radioactive release. Personal doses are obtained from engineering calculations

Development of Computer Code Input Data Decks (RELAP5)



* Verification includes internal verification and external review
  Validation includes simulation of well documented transient for reference plant

Grouping of Events

- Grouping of initiating events is based on leading physical phenomena induced by event itself:
  - Increase in heat removal by secondary side
  - Decrease in heat removal by secondary side
  - Decrease in reactor coolant flow rate
  - Reactivity and power distribution anomalies
  - Increase in reactor coolant inventory
  - Decrease in reactor coolant inventory
  - Anticipated transients without scram
  - Radioactivity release from subsystem and components

Categorization of Events

- Using results of PRA Level 1, initiating events of each group are classified based on anticipated frequency of occurrence:
  - Transients - violations of normal operation, which are expected to occur during plant life time (i.e., expected frequency of occurrence not less than $3.3 \cdot 10^{-2}$ $year^{-1}$)
  - Accidents - low probability events, which are not expected to occur during plant life time (i.e., expected frequency of occurrence less than $3.3 \cdot 10^{-2}$ $year^{-1}$)

Acceptance Criteria

- Acceptance criteria are aimed to prevent damage of safety barriers (i.e., fuel, cladding, reactor coolant pressure boundary, containment) against uncontrolled release of radioactivity, and radiological impact

- More stringent requirements are applied to events with higher anticipated frequency of occurrence

List of Acceptance Criteria

- Fuel integrity is ensured
  - Maximum fuel temperature should not exceed UO_2 melting point (i.e., 2840 °C for fresh fuel, and 2570 °C for burned fuel) at any axial location within any fuel rod
  - Maximum radially-averaged fuel enthalpy should not exceed 963 kJ/kg (230 cal/g) for fresh fuel, and 840 kJ/kg (200 cal/g) for burned fuel at any axial location within any fuel rod
- Fuel cladding integrity is ensured
  - Minimum DNBR should remain higher than 1.0 with confidence probability not less than 95%
  - Maximum fuel clad temperature should not exceed 1200 °C at any axial location within any fuel rod
- Integrity of primary and secondary system pressure boundary is ensured
  - Pressure in reactor coolant system should not exceed 115% of design pressure (i.e., 207 bar for SUNPP-1, and 158 bar for RNPP-1)
  - Pressure in steam generator secondaries and main steam system should not exceed 115% of design pressure (i.e., 92 bar for SUNPP-1, and 63 bar for RNPP-1)
- Containment integrity is ensured
  - Pressure of steam-gas mixture should not exceed 5.0 bar for SUNPP-1, and 2.5 bar for RNPP-1
  - Temperature of steam-gas mixture should not exceed 150°C for SUNPP-1, and 127°C for RNPP-1
- Allowed radioactive doses are not exceeded at boundary of protection zone:
  - Equivalent personal doses calculated for the worst meteorological conditions should not exceed 0.3 Sv/year (30 REM/year) for child thyroid due to inhalation, and 0.1 Sv/year (10 REM/year) for whole body due to external irradiation

Analysis of Events

- Based on engineering judgement, initiating events are classified into two broad groups:
  - Quantitatively analyzed events, which may potentially challenge the acceptance criteria
  - Qualitatively analyzed events, which produce definitely less severe consequences

Documentation of Results
(Quantitative analysis)

- Each Summary report presents structured information to meet documentation requirements:
  - General characteristic of events, addressing impact of events on the safety barriers
  - Acceptance criteria applied
  - Selection of initial and boundary conditions for analytical model
  - Analysis of transient progression
  - Conclusions on that how the acceptance criteria are met
  - Plots of calculation results

Status Of DBA Analyses

DBA Initiating Event Group	RNPP-1	SUNPP-1
Increase in heat removal by secondary side	**Review in progress**	**Review in progress**
Decrease in heat removal by secondary side	Analysis in progress	**Review in progress**
Decrease in reactor coolant flow rate	**Completed**	**Completed**
Reactivity and power distribution anomalies	**Review in progress**	**Completed**
Increase in reactor coolant inventory	**Completed**	**Completed**
Decrease in reactor coolant inventory	**Review in progress**	Analysis in progress
Anticipated transients without scram	Analysis in progress	**Completed**
Radioactivity release from subsystem and components	Analysis in progress	Analysis in progress

Increase in heat removal by secondary side

Type of analysis and compliance to acceptance criteria

Initiating Event	Category/ Frequency*	Type of analysis	DNBR	Pprimary	Psecondary	T fuel	P cont	T cont	# of calculations
Main steam line break	A/ $8 \cdot 10^{-3}$	Quantitative	OK	OK	OK	OK	OK	OK	5
SG SV stuck open	T/ $7.7 \cdot 10^{-2}$	Quantitative	OK	OK	OK	OK	–	–	1
BRU-K stuck open	T/ $7.7 \cdot 10^{-2}$	Quantitative	OK	OK	OK	OK	–	–	1
BRU-A stuck open	T/ $7.7 \cdot 10^{-2}$	Engineering Analysis							
Control system malfunctions resulting in an increase in turbine steam flow	T/ $2.9 \cdot 10^{-2}$	Engineering Analysis							
FW system malfunctions resulting in a decrease in FW temperature	T/ $8.1 \cdot 10^{-2}$	Engineering Analysis							
FW system malfunctions resulting in an increase in FW flow	T/ $4.5 \cdot 10^{-2}$	Engineering Analysis							

*IE frequencies are taken from Rivne NPP Unit 1 probabilistic risk assessment.

Decrease in heat removal by secondary side

Type of analysis and compliance to acceptance criteria

Initiating Event	Category/ Frequency	Type of analysis	DNBR	Pprimary	Psecondary	P cont	Tcont	# of calculations
Loss of external load	T/ $9.7 \cdot 10^{-2}$	Quantitative	OK	OK	OK	–	–	2
Loss of nonemergency AC power supply	T/ $2.9 \cdot 10^{-2}$	Quantitative	OK	OK	OK	–	–	1
Inadvertent closure of FASIV	T/ $3.4 \cdot 10^{-2}$	Quantitative	OK	OK	OK	–	–	1
Loss of turbine condenser vacuum	T/ $5.5 \cdot 10^{-2}$	Quantitative	OK	OK	OK	–	–	2
Trip of one turbine	T/ 1.72	Engineering Analysis						
Feedwater pipeline breaks inside and outside containment	A/ $1.3 \cdot 10^{-3}$	Quantitative	OK	OK	OK	OK	OK	6
Trip of one MFW pump	T/ 0.409	Engineering Analysis						
Decrease in FW flow to one SG	T/ $8.7 \cdot 10^{-2}$	Engineering Analysis						

Decrease in a reactor coolant flow rate

Type of analysis and compliance to acceptance criteria

Initiating Event	Category/ Frequency	Type of analysis	DNBR	Pprimary	Psecondary	# of calculations
Trip of three or less MCP	T/ 0.5	Quantitative	OK	OK	OK	6
Break of MCP shaft	A/ $8.8 \cdot 10^{-3}$	Quantitative	OK	OK	OK	2
Trip of four or more MCP	T/ $9.8 \cdot 10^{-2}$	Quantitative	OK	OK	OK	2
MCP rotor seizure	A/ $6.4 \cdot 10^{-3}$	Quantitative	OK	OK	OK	2
Inadvertent closure of MGV	A/ $7.9 \cdot 10^{-3}$	Engineering Analysis				

Reactivity and power distribution anomalies

Type of analysis and compliance to acceptance criteria

Initiating Event	Category/ Frequency	Type of analysis	DNBR	Pprimary	Psecondary	Tfuel	I_{UO2}	# of calculations
Control assembly ejection	A/ $7.9 \cdot 10^{-3}$	Quantitative	OK	OK	OK	OK	OK	5
Start-up of inactive RCS loop	T/ $1.2 \cdot 10^{-2}$	Quantitative	OK	OK	OK	–	–	2
Uncontrolled withdrawal of control assembly group	T/ $1.8 \cdot 10^{-2}$	Quantitative	OK	OK	OK	–	–	6
CVCS malfunctions resulting in a decrease in boron concentration	T/ $1.2 \cdot 10^{-2}$	Engineering Analysis						

Increase in reactor coolant inventory

Type of analysis and compliance to acceptance criteria

Initiating Event	**Category/ Frequency**	**Type of analysis**	**DNBR**	**Pprimary**	**Psecondary**	**# of calculations**
Spurious operation of HPIS	T/ $1 \cdot 10^{-2}$	Quantitative	OK	OK	OK	1
CVCS malfunctions resulting in an increase in reactor coolant inventory	T/ $2.9 \cdot 10^{-2}$	Quantitative	OK	OK	OK	1

Decrease in reactor coolant inventory

Type of analysis and compliance to acceptance criteria

Initiating Event	Category/ Frequency	DNBR	Psecondary	PCT	Pcont	Tcont	# of calculations
Break of I&C pipe (13mm)	T/ 0.26	OK	–	–	–	–	1
Drainage system line break (25mm)	A/ $3 \cdot 10^{-3}$	–	–	OK	–	–	1
Make-Up system line break (73mm)	A/ $3 \cdot 10^{-3}$	–	–	OK	–	–	1
Break of pipeline between PRZ and PRZ PORV (88mm)	A/ $4.2 \cdot 10^{-4}$	–	–	OK	–	–	1
PRZ spray line break (90mm)	A/ $4.2 \cdot 10^{-4}$	–	–	OK	–	–	1
PRZ safety valve stuck open	A/ $2.4 \cdot 10^{-2}$	–	–	OK	–	–	2
HPIS line break (113mm)	A/ $4.2 \cdot 10^{-4}$	–	–	OK	–	–	1
HA surge line break (233mm)	A/ $9.7 \cdot 10^{-5}$	–	–	OK	–	–	1
PRZ surge line break (277mm)	A/ $9.7 \cdot 10^{-5}$	–	–	OK	–	–	1
DEGB of cold leg (2×500mm)	A/ $9.7 \cdot 10^{-5}$	–	–	OK	OK	OK	2
DEGB of hot leg (2×500mm)	A/ $9.7 \cdot 10^{-5}$	–	–	OK	OK	OK	2
SG tube rupture	T/ $4 \cdot 10^{-2}$	OK	–	–	–	–	1
SG collector cover lift-up	A/ $5 \cdot 10^{-3}$	–	OK	OK	–	–	2

Anticipated transients without scram

Type of analysis and compliance to acceptance criteria

Initiating Event	**Category/ Frequency**	**Type of analysis**	**PCT**	**Pprimary**	**Psecondary**	**# of calculations**
Trip of four or more MCP	A/ $3 \cdot 10^{-6}$	Quantitative	OK	OK	OK	1
Loss of turbine condenser vacuum	A/ $1.5 \cdot 10^{-6}$	Quantitative	OK	OK	OK	2
Loss of feedwater flow	A/ $3.7 \cdot 10^{-6}$	Quantitative	OK	OK	OK	1
Turbine trip	A/ $1 \cdot 10^{-5}$	Quantitative	OK	OK	OK	1
Loss of external load	A/ $3.1 \cdot 10^{-6}$	Engineering Analysis				

Radioactivity release from subsystem and components

Compliance to acceptance criteria

Initiating Event	**Category/ Frequency**	**Personal Dose**
Steam line break outside containment	A/ $8 \cdot 10^{-3}$	OK
DEGB of RCS loop	A/ $9.7 \cdot 10^{-5}$	In progress
Steam generator collector cover lift-up	A/ $5 \cdot 10^{-3}$	In progress
Let-down system line break outside containment	A/ $1.7 \cdot 10^{-2}$	In progress

Increase in heat removal by secondary side

Type of analysis and compliance to acceptance criteria

Initiating Event	Category/ Frequency*	Type of analysis	DNBR	Pprimary	Psecondary	T fuel	P cont	T cont	# of calculations
Main steam line break	A/ $4.4 \cdot 10^{-4}$	Quantitative	OK	OK	OK	OK	OK	OK	2
MSH break	A/ $4.4 \cdot 10^{-4}$	Quantitative	OK	OK	OK	OK	–	–	1
BRU-K stuck open	T/ $3.1 \cdot 10^{-2}$	Quantitative	OK	OK	OK	OK	–	–	1
BRU-A stuck open	T/ $3.1 \cdot 10^{-2}$	Quantitative	OK	OK	OK	OK	–	–	1
SG SV stuck open	T/ $3.1 \cdot 10^{-2}$	Engineering Analysis							
FW system malfunctions resulting in a decrease in FW temperature	T/ 0.17	Engineering Analysis							
FW system malfunctions resulting in an increase in FW flow	T/ 0.13	Engineering Analysis							

*IE frequencies are taken from SUNPP Unit 1 probabilistic risk assessment.

Decrease in heat removal by secondary side

Type of analysis and compliance to acceptance criteria

Initiating Event	Category/ Frequency	Type of analysis	DNBR	Pprimary	Psecondary	P cont	Tcont	# of calculations
Loss of external load	T/ $8.7 \cdot 10^{-2}$	Quantitative	OK	OK	OK	–	–	1
Inadvertent closure of TSV	T/ 0.54	Engineering Analysis						
Loss of nonemergency AC power	T/ $1.0 \cdot 10^{-2}$	Quantitative	OK	OK	OK	–	–	1
Inadvertent closure of FASIV	T/ $3.7 \cdot 10^{-2}$	Quantitative	OK	OK	OK	–	–	1
Loss of turbine condenser vacuum	T/ 0.12	Quantitative	OK	OK	OK	–	–	1
Feedwater pipeline break inside containment	A/ $6 \cdot 10^{-3}$	Quantitative	OK	OK	OK	OK	OK	2
Feedwater system malfunctions resulting in a decrease in FW flow	T/ 0.14	Engineering Analysis						
Main feedwater collector break	A/ $(5\ldots7) \cdot 10^{-3}$	Quantitative	OK	OK	OK	–	–	1

Decrease in a reactor coolant flow rate

Type of analysis and compliance to acceptance criteria

Initiating Event	Category/ Frequency	Type of analysis	DNBR	Pprimary	Psecondary	# of calculations
Trip of two out four MCP	T/ 0.15	Quantitative	OK	OK	OK	1
Trip of one MCP	T/0. 21	Engineering Analysis				
Trip of four MCP	T/ $1 \cdot 10^{-3}$	Quantitative	OK	OK	OK	1
MCP rotor seizure	A/ $9.9 \cdot 10^{-3}$	Quantitative	OK	OK	OK	1
Inadvertent closure of MGV	A/ $8.8 \cdot 10^{-3}$	Engineering Analysis				
Break of MCP shaft	A/ $2.5 \cdot 10^{-3}$	Quantitative	OK	OK	OK	1

Reactivity and power distribution anomalies

Type of analysis and compliance to acceptance criteria

Initiating Event	Category/ Frequency	Type of analysis	DNBR	Pprimary	Psecondary	Tfuel	I_{UO2}	# of calculations
Control rod ejection	A/ -	Quantitative	OK	OK	OK	OK	OK	1
Start-up of inactive RCS loop	T/ -	Quantitative	OK	OK	OK	–	–	1
Uncontrolled withdrawal of control rod group	T/ $1 \cdot 10^{-2}$	Quantitative	OK	OK	OK	–	–	1
CVCS malfunctions resulting in a decrease in boron concentration	T/ $1 \cdot 10^{-2}$	Engineering Analysis						

Increase in reactor coolant inventory

Type of analysis and compliance to acceptance criteria

Initiating Event	Category/ Frequency	Type of analysis	DNBR	Pprimary	Psecondary	# of calculations
CVCS malfunctions resulting in an increase in reactor coolant inventory	T/-	Quantitative	OK	OK	OK	1
Spurious operation of HPIS	T/1·10^{-2}	Engineering Analysis				

Decrease in reactor coolant inventory

Type of analysis and compliance to acceptance criteria

Initiating Event	Category	DNBR	Psecondary	PCT	Pcont	Tcont	# of calculations
Break of I&C pipe (13mm)	T/ 0.21	OK	–	–	–	–	1
Drainage system line break (32mm)	A/ $3 \cdot 10^{-3}$	–	–	OK	–	–	1
Make-up system line break (64mm)	A/ $4.2 \cdot 10^{-4}$	–	–	OK	–	–	1
PRZ safety valve stuck open	A/ $1.7 \cdot 10^{-2}$	–	–	OK	–	–	1
HPIS line break (133mm)	A/ $4 \cdot 10^{-6}$	–	–	OK	–	–	1
PRZ spray line break (181mm)	A/ $4 \cdot 10^{-6}$	–	–	OK	–	–	1
HA surge line break (279mm)	A/ $4 \cdot 10^{-6}$	–	–	OK	–	–	1
PRZ surge line break (346mm)	A/ $4 \cdot 10^{-6}$	–	–	OK	–	–	1
DEGB of cold leg (2×850mm)	A/ $4 \cdot 10^{-6}$	–	–	OK	–	–	1
DEGB of hot leg (2×850mm)	A/ $4 \cdot 10^{-6}$	–	–	OK	OK	OK	1
SG tube rupture (2×13mm)	T/ $4.6 \cdot 10^{-2}$	OK	OK	–	–	–	1
SG collector cover lift-up (80mm)	A/ $2 \cdot 10^{-3}$	–	OK	OK	–	–	1

Anticipated transients without scram

Type of analysis and compliance to acceptance criteria

Initiating Event	Category/ Frequency	Type of analysis	PCT	Pprimary	Psecondary	# of calculations
Loss of feedwater flow	A/ $3 \cdot 10^{-6}$	Quantitative	OK	OK	OK	1
Loss of turbine condenser vacuum	A/ $3.7 \cdot 10^{-6}$	Quantitative	OK	OK	OK	1
Turbine trip	A/ $1.7 \cdot 10^{-5}$	Engineering Analysis				
Inadvertent closure of FASIV	A/ $1.2 \cdot 10^{-6}$	Engineering Analysis				
Loss of external load	A/ $2.7 \cdot 10^{-6}$	Engineering Analysis				

Radioactivity release from subsystem and components

Compliance to acceptance criteria

Initiating Event	**Category/ Frequency**	**Personal Dose**
Steam line break outside containment	A/ $4.4 \cdot 10^{-4}$	OK
DEGB of RCS loop	A/ $4 \cdot 10^{-6}$	In progress
Steam generator collector cover lift-up	A/ $2 \cdot 10^{-3}$	In progress
Let-down system line break outside containment	A/ $1 \cdot 10^{-3}$	In progress